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ES&H Section

RP. NOTE 154

Estimation of the Air Emissions from the operation of MI 8 GeV line Collimators

Kamran Vaziri

(August 2009)

Author: ____________________ Date: 8/13/'09
K. Vaziri

Reviewed: ____________________ Date: 8/13/09
D. Cossairt

Approved: ____________________ Date: 8/13/09
D. Cossairt
Associate Head for Radiation Protection

Approved: ____________________ Date: 8/13/09
Nancy Grossman
Head, ES&H Section

Distribution via Electronic Mail*

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I. Introduction

In order to improve the quality of the proton beam from the Booster to the Main Injector two sets of collimators are installed in the MI-8GeV transport line. These collimators, which are located at MI-836 and MI-838 are designed to remove the beam halo [1].

There are several radiological issues that are related to design goals of this collimator system. Contamination of the surface water, ground water, residual activation and prompt radiation are reviewed in references [2,3]. This note describes the calculations for the air activation levels caused by the interaction of radiation leaking out of the collimator shielding with air, and various release estimates.

Figure 1. shows that air flow in the MI-8 tunnel is achieved by exhaust and supply fan systems of 5000 cfm capacity to supplement the air flow from openings to the Booster tunnel, the MI-8 major vehicle access and the Main Injector tunnel [4]. In sequence, the fan systems are Makeup unit 9 (MU-9) which puts air in at Q805, Exhaust Fan 10 (EF-10) from the region of Q817, an injector at Q823 (MU-8), an exhaust (EF-9) at Q837 (on the surface it is at the southeast side of the MI-8 Service Building) and an injector at Q843 (MU-7). MU-1 provides air at Q101 and EF-6 removes air at Q624 in the Main Injector Tunnel.

Calculations

The air activation levels is analyzed assuming a loss of 1% of the beam on each collimator pair or a total of 2% of the Booster beam which is assumed as 5E12 protons per pulse with a repetition rate of 10 Hz. Therefore, the activity is due to 1E12 protons/sec loss of 8 GeV beam on the two collimators at 836 and two at 838. The radiation loss is modeled using the MARS code [3]. It is assumed that the MI-8 GeV line operates 2E7 sec/yr, is 2190 ft. long and has a cross section of 80 square feet [1,2]

Figures 2 and 3 show the hadron fluxes in the air due to loss of 5E11 protons/sec. on the collimators. The details of modeling and the results are given in TM-2359 [2]. These fluxes were used for the airborne radionuclides production calculations.

The composition of the air is given in Table 1. Table 2 gives values of decay constants and radionuclide production cross sections from different elements. The production cross-sections are conservative choices taken from the references by Barbier [5] and Thomas and Stevenson [6]. ^{41}Ar has a large cross section for production by thermal neutrons. It is usually difficult and time consuming to estimate the thermal neutron flux densities using MARS, and thus a scaling factor is used. The value of the concentration of ^{41}Ar is conservatively taken to be 2.5 % of the sum of the concentrations of ^{11}C and ^{13}N calculated within a given enclosure. This choice is conservative in that typical measured values at Fermilab are about 1% to 2%. For the annual dose to the maximally exposed individual offsite ^{41}Ar, ^{13}N and ^{11}C are the most radiologically significant radionuclides. However, the released activity concentrations of ^{15}O, ^{7}Be and ^{3}H are also calculated.

Table 1. The isotopic composition of air in fraction of atoms and atom density.

Nuclide	Atomic weight	Total Fractional atoms	Atoms/cm^3
^{14}N	14	78.1903	4.1805E+19
^{15}N	15	0.2872	1.5357E+17
^{16}O	16	21.0031	1.1230E+19
^{17}O	17	0.0080	4.2774E+15
^{18}O	18	0.0421	2.2513E+16
^{36}Ar	36	0.0016	8.4443E+14
^{38}Ar	38	0.0003	1.5860E+14
^{40}Ar	40	0.4675	2.4994E+17

The number of radionuclides of each type produced is calculated by summing over the contributions from different target nuclides in air: The concentration of the radionuclide "i" is calculated using

$$a_i(Bq/yr)=\sum_j\left(N_j\sigma_{ij}\ \phi\ N_p O_s\right)\left[e^{-\lambda_i t_{cool}}\right]\left[\left(\frac{\lambda_i}{\lambda_i+r}\right)\left(1-e^{-(\lambda_i+r)t_{irrad}}\right)\right]\left[\left(e^{-\lambda_i t_{transit}}\right)D\right]$$

N_p is the number of protons per second.

ϕ is the hadron flux density (hadrons/cm^2/proton).

N_j is the number of target atoms per unit volume (atoms/cm^3).

σ_{ij} is the cross section for production of radionuclide i from target atom j (cm^2).

λ_i is the inverse mean lifetime of radionuclide i (seconds^{-1}).

t_{cool} is the time after beam-off at which one is calculating the release; typically this is zero as one calculates for a continuous beam-on release.

t_{irrad} is the irradiation time of the air volume.

r the ventilation term, is the number of air changes per unit time.

$$r=\frac{D}{V}$$

D is the ventilation rate in the external air volume per unit time.

V is the volume of region (cm^3).

O_s is the number of operational (beam-up) seconds year.
$t_{transit}$ is the ventilation system travel time, from the production region to the release point:

$$t_{transit} = \frac{V}{D}$$

Table 2. Decay constants and the cross sections for the production of various airborne radioisotopes from air.

	Decay Constants, λ_i, and Derived Air Concentration[a] (DAC) Limits for Various Radionuclides					
Product =>	^{3}**H**	^{7}**Be**	^{11}**C**	^{13}**N**	^{15}**O**	^{41}**Ar**
λ (sec^{-1}) =>	1.79E-9	1.51E-7	5.69E-4	1.16E-3	5.67E-3	1.05E-4
DAC (Ci/cm3)	2E-11[b]	1E-11	5.9E-11	4.1E-11	2.7E-11	4.7E-11
Target Nuclide	**High Energy Hadron Cross Sections (mb)**					
^{14}N	30	14	20	4	0	
^{16}O	30	8	10	5	35	
^{17}O	30	8	10	5	35	
^{40}Ar[c]	1	10	1	1	1	610
^{15}N	30	14	20	4	0	
^{18}O	30	8	10	5	35	

[a] From Reference [7].

[b] This is the value for the tritiated water, which is a more conservative value than the DAC for the elemental form.

[b] Conservatively assumed all Argon isotopes as ^{40}Ar.

IV Analysis of the results

The activation products are ^{41}Ar, ^{11}C, ^{13}N, ^{15}O, ^{7}Be and tritium. The radioisotope ^{7}Be is 0.03% of total activity produced. Most of the ^{7}Be plates out near the production location and does not reach the release point. Tritium is 0.001% of the total activation products. The short half-life of ^{15}O and the small decay constant of ^{3}H usually result in radiologically insignificant releases of these two radionuclides. The released air activity is usually dominated by ^{11}C, ^{13}N, ^{41}Ar and ^{15}O. Figure **4**. shows the amount of annual activated air released due to the operation of the collimators as a function of air flow rate in this region of the MI-8 line.

The air supply is located in the middle of the collimators region [Fig. 4.]. The air flowing into the tunnel splits in two 2500 cfm currents flowing in opposite directions in the tunnel. Each half of the supply air will flow over half of the collimators region and travels a total distance of 853 ft. to the nearest exhaust [2]. This would correspond to 17.5 minutes of transit/decay time for each direction. Note, with the fan running the total volume of the enclosure will refresh 3.4 times an hour. With the fans off, natural air exchange is about one exchange per hour.

IV. Conclusion

The maximum annual release with the fans set at 5000 cfm is 1.24 Ci/yr, which is a relatively small amount. However, the fans are single velocity; off or 5000 cfm. These fans are normally off. If they are left off and the exhaust vents are open (or the transport line is not sealed) a natural air exchange would correspond to 0.26 Curies/yr release.

In about half of a day of beam operations ^{41}Ar, ^{11}C, ^{13}N and ^{15}O activities have reached saturation levels. Under the current air flow scheme of the MI-8 GeV line (fans off), thirty minutes after the beam is shut off (after one day or longer of continuous operations) the residual radioactive air decays below 10% of DAC, which would not require any monitoring or "Air Contamination" postings [8]. In order to clear the 8-GeV line from residual activated air, after the beam is turned off, the fans should run at 5000cfm for at least 20 minutes (one air exchange).

By keeping track of the losses on the collimators, the released activity can be estimated and accounted for in the annual NESHAP [9] report as unmonitored releases.

References

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8. "Fermilab Radiological Control Manual," http://www-esh.fnal.gov/FRCM/.
9. United States Code of Federal Regulations, Title 40, Part 61, Subpart H, "National emissions standard for hazardous air pollutants (NESHAP) for the emission of radionuclides other than radon from Department of Energy Facilities", 1989.

Figure 1. Drwing showing the MI-8 GeV from Booster to the Main Injector. Locations of the air Supply Fans (SF) and air Exhaust Fans (EF) are shown [4].The red dot shows the air supply fan located between the two collimators.

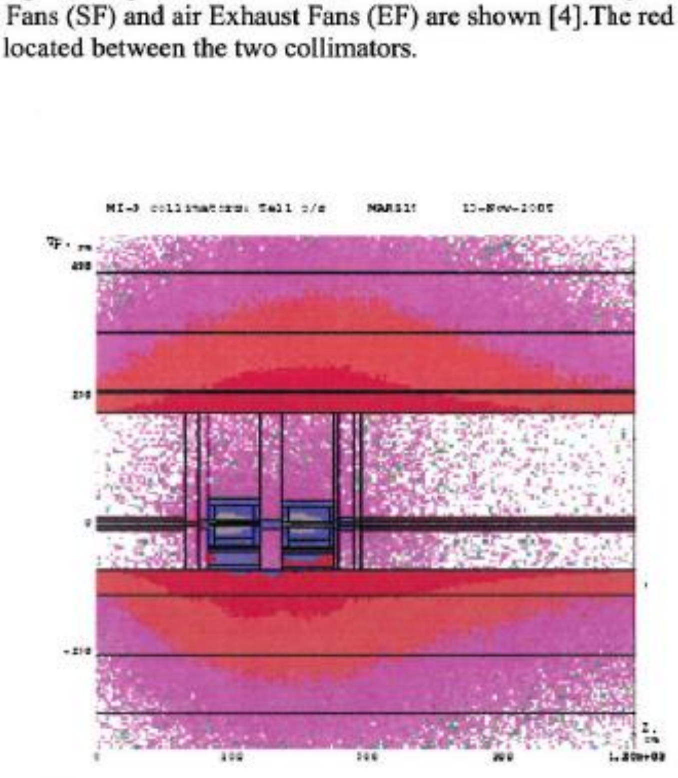

Figure 2. Longitudinal star density distribution in and around the MI-8 GeV Line due to beam losses on the collimators.

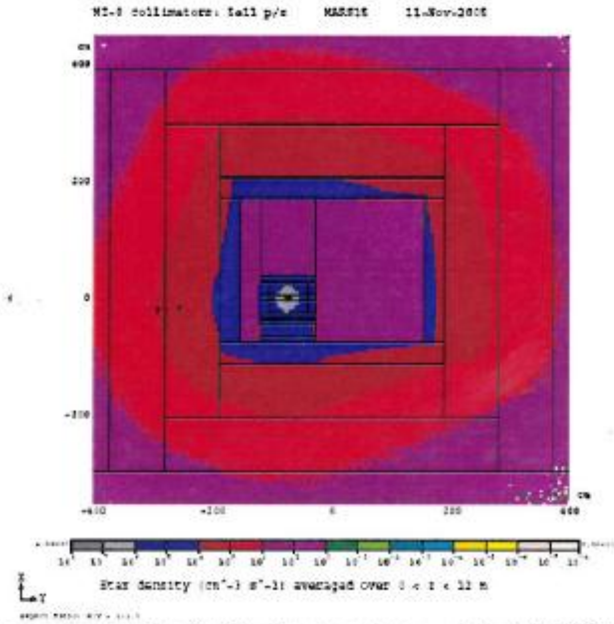

Figure 3. Transverse star density distribution in and around the MI-8 GeV Line due to beam losses on the collimators.

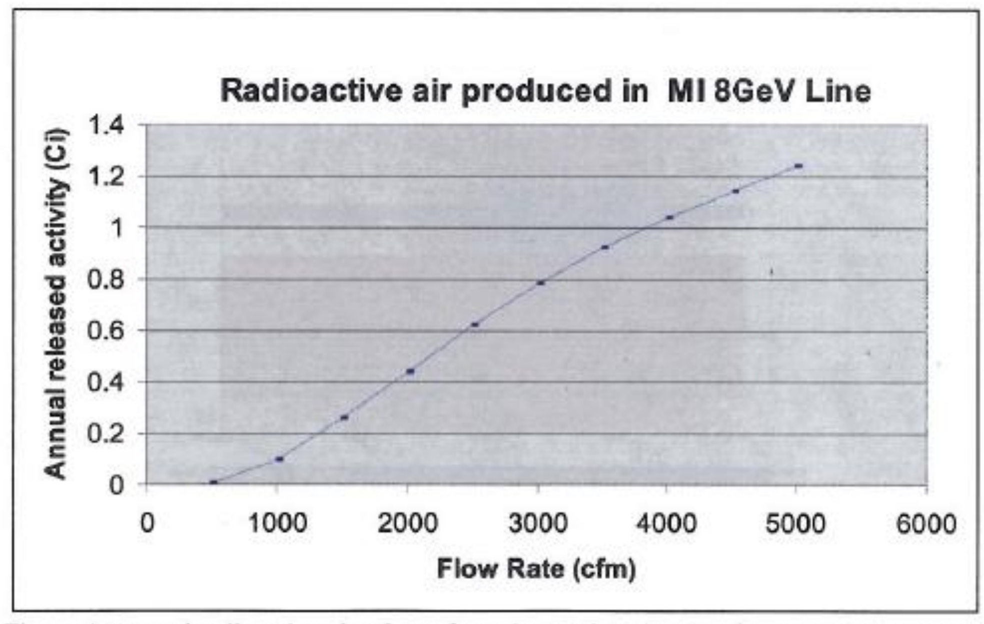

Figure 4. Annual radioactive air release from the MI-8 region as a function of supply air flow rate for two ventilation scenarios.